Palaeolimnological responses of nine North African lakes in the CASSARINA Project to recent environmental changes and human impact detected by plant macrofossil, pollen, and faunal analyses

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Abstract

This paper presents multi-proxy palaeolimnological analyses from recent sediments in the nine CASSARINA lakes in northernmost Africa, three from each of Morocco, Tunisia, and Egypt. The lakes are diverse, ranging from hypersaline to brackish lagoons and fresh-water lakes from high to low conductivity and pH. The macrofossils analysed include fruits, seeds, and vegetative remains of plants, lagoon and fresh-water Mollusca, a range of other aquatic animals, and from one site in each country, Ostracoda and Foraminifera. The diverse macrofossils are multi-proxy indicators of environmental change, and demonstrate changes in response to human activities in the catchments of all the lakes. The three Egyptian Nile Delta lakes have received massive inputs of fresh-water due to modifications of the flow of the R. Nile culminating in the Aswan High Dam built in 1964. Elsewhere, water withdrawal is frequently a serious threat. One lake with high biodiversity in Morocco has been drained and cultivated, and a rare acid-water lake in Tunisia is in danger of drying up. The internationally famous Garaet El Ichkeul in Tunisia, which was so important for birds, has become permanently saline with a loss of diversity. All the lakes are affected by agricultural and/or urban run-off and are experiencing changes as a result of human activities. Several are in a marginally sustainable condition, whereas others are permanently damaged.

Introduction

Water is a valuable resource in dry countries. Lakes and rivers are under increasing threat in North Africa from water withdrawal for human use, and secondarily from eutrophication, pollution, and destruction of surrounding wetlands. The CASSARINA (Change, Stress, and Sustainability: Aquatic Ecosystem Resilience in North Africa) Project (Flower, 2001) aims to describe lake ecosystem changes in nine North African lakes over the last century and relate these to environmental changes and human impacts (stress) in their catchments. Such information is basic to the drawing up of wetland management and conservation plans. These need to be carefully considered, particularly in N. Africa, where technology is developing rapidly and where the understanding of aquatic ecosystems and the effects that exploitation and management will have on them is relatively poor (Mitchell et al., 1985).

Lakes are scarce in North Africa and are valued as sources of water and of food (fish). They are also 'islands' of high habitat diversity and hence high biodiversity, and are therefore notable refuges for aquatic plants and animals as well as important habitats for birds, particularly those migrating to and from Europe. Other papers in this volume describe the historical and pollen records of major events in the catchments of nine lakes over the last century of accelerated technological development (Ramdani et al., 2001a; Peglar et al., 2001). Lake responses to these events can be traced by stratigraphical analyses of short sediment cores from the lakes. Diatoms (Flower et al., 2001), zooplankton and benthos (Ramdani et al., 2001b), pollen (Peglar et al., 2001), and meiobenthos and larger animal and plant macrofossils (this paper) were analysed stratigraphically. Chronologies were provided by radiometric (210Pb) dating and event stratigraphy (Appleby et al., 2001). Within this framework, this paper presents the palaeolimnological analyses of plant and animal macrofossils and aquatic pollen from short sediment cores, in an attempt to describe lake ecosystem responses to recent environmental changes and external stresses, to assess their resilience or otherwise to continued pressures, and to evaluate their likely sustainability if present environmental stresses remain constant. The relative amounts of change within a lake are summarised numerically in an attempt to make comparisons between lakes by Birks et al., 2001.

Methods

The locations and the present environments and lake ecosystems are described by Ramdani et al. (2001a, c). Their main characteristics are summarised in Table 1. Short (ca. 1 m) lake-sediment cores were taken with a modified Livingstone piston corer (Flower & Patrick, 1997; Flower, 2001). Usually the last 100 years were represented, but sometimes more if the sedimentation rate was slow. The second core of an adjacent pair was divided into 2 cm sections, except for Burullus Lake where the second core was near the shore (Peglar et al., 2001). The sediments were described visually, and analysed by loss-on-ignition (LOI) to describe their lithostratigraphy. Bulk density was calculated from weight loss after drying at 105ºC; organic carbon was estimated by LOI at 550ºC; inorganic carbon (carbonate) was estimated by LOI at 950ºC. The source of carbonate is mainly precipitated lake marl and calcareous shells. The results are presented in Flower et al. (2001) and Birks et al. (2000).

For macrofossil analyses, a known volume of sediment (usually ca. 25 cm^3) was suspended in water and washed gently through a sieve of 125 μmmesh diameter. The retained material was examined systematically under a stereo-microscope at 12x magnification and macrofossils of interest (fruits and seeds, some vegetative remains of plants, chitinous animal remains, and mollusc shells) were picked out. Ostracoda and Foraminifera were not systematically extracted, but samples from Merja Bokka (Morocco), Garaet El Ichkeul (Tunisia), and Manzala Lake (Egypt) were quantitatively analysed as percentages for these organisms from the sieved residues. Discrete macrofossil remains were counted but vegetative parts and animal remains of chironomids, other insect parts, fish bones, ostracods, foraminifera, and broken shells were estimated in five abundance classes (rare, occasional, frequent, abundant, very abundant). All plant macro remains are reproductive propagules unless otherwise stated. The data were calculated to a constant volume (50 or 100 cm3) and, together with aquatic pollen data from the same cores, were plotted stratigraphically using TILIA software (Grimm, 1990). Standard pollen analytical methods were used (Peglar et al., 2001). Vascular plant

nomenclature follows Flora Europaea (1964–1980) or more recent but incomplete floras of Morocco (Fennane et al., 1999) and Egypt (Boulos, 1999).

Radiometric dating aided by biostratigraphic events (e.g., exotic pollen occurrence) provided chronologies (Appleby et al., 2001) for the primary cores. The lithostratigraphic changes in the adjacent secondary cores were comparable, so it was felt justified to transfer the dates to them. The second Burullus Lake core (BURL-2) was dated directly (Appleby et al., 2001).

Table 1. Characteristics of the nine CASSARINA lakes, arranged from west to east

	Sidi Bou Rhaba	Zerga	Bokka	Chitane	Ichkeul	Korba	Edku	Burullus	Manzala
Country	Morocco	Morocco	Morocco	Tunisia	Tunisia	Tunisia	Egypt	Egypt	Egypt
Size	200 × 1500 m	9 × 5 km	250m in diameter	90 × 90 m	15 × 5 km	6.4 × 0.5 km	19 × 6 km	56 × 10 km	47 × 30 km
Area (km^2)	1.5	20-22	0.05	0.025	89	0.32	126	570	1200
Type	lake	lagoon	lake	lake	lagoon	lagoon	lagoon	lagoon	lagoon
Water	fresh calcareous	saline	fresh calcareous	fresh soft	saline	hypersaline	fresh calcareous	brackish	fresh calcareous
Depth range (m)	0.2–2.0	0.3–0.8	0.2–0.9 (pre 1998)	0.4–1.0	0.1–0.8	0.15–0.85	0.5–2.0	0.5–1.6	0.7–1.5

Results and discussion

Sidi Bou Rhaba (Morocco) 34°12'N, 6°42'E (Figure 1)

The radiometric dates indicate that sediment below ca. 100 cm (zone 1) in core RHAB-3 was deposited before 1860. The abundance of *Chara*-type oospores indicate that charophyte algae (probably *Chara aspera* that is still common in the lake today) dominated the macrophyte vegetation. Intermixed were *Potamogeton*, *Najas armata*, and *Ruppia*, which probably fluctuated in abundance through the year as they do today (Ramdani et al., 2001a). The presence of *Typha* and *Juncus* (probably *J. maritimus* and/or *J. acutus*) (seeds) (Figure 1) and *Phragmites* (pollen) (Peglar et al., 2001) indicate a marginal reed-marsh. The lake water was probably clear and calcareous, and supported abundant invertebrates. The Cladocera ephippia probably belong to *Ceriodaphnia dubia* (Ramdani et al., 2001b). Ostracods, aquatic oribatid mites, and the bryozoan *Plumatella* were particularly abundant. The ostracods are fresh-water to oligohaline species dominated by *Potamocypris arcuata*, *Sarscypridopsis aculeata*, and *Eucypris virens* (Ramdani et al., 2001b). Gastropods characteristic of calcareous fresh-water were present throughout (M. Ramdani, unpubl.).

Above 100 cm (zone 2) concentrations of *Chara*type oospores, mites, *Plumatella*, and ostracods fall markedly. The presence of *Zannichellia* may suggest some local disturbance and possibly an increase in salinity that this plant thrives on. *Ruppia*, *Najas armata* (leaf-spine records only), and *Potamogeton* were still present. The presence of shallow water and exposed littoral mud is suggested by the occurrence of *Ranunculus* sect. *Batrachium*, and the record of *Ceratophyllum* may indicate increased nutrient levels. Disturbance is also indicated after 1860 by the expansion of the opportunist cladoceran *Chydorus sphaericus* (Ramdani et al., 2001b), and an increase in salinity is suggested in the diatom record (Flower et al., 2001). The lake was productive and sedimentation was rapid (ca. 0.35 cm yr^{-1}; Appleby et al., 2001). Shallowing water and introduction of fish, especially bottomfeeders (Ramdani et al., 2001a) may have tipped the previous equilibrium of a clear-water lake dominated by macrophytes to a turbid-water condition where the expansion of planktonic algae reduced light penetration (Scheffer et al., 1993). The lake is turbid today due to high phytoplankton biomass, dominated by the cyanobacterium *Microcystis aeruginosa* (Fathi et al., 2001). At the lake margin, *Juncus* spp. increased markedly, together with *Typha* (Figure 1), whereas *Phragmites* apparently declined (Peglar et al., 2001). These developments may reflect natural hydroseral succession as sediment filled the basin, or may have been accelerated locally by the building of the road across the lake in 1917 (Ramdani et al., 2001a).

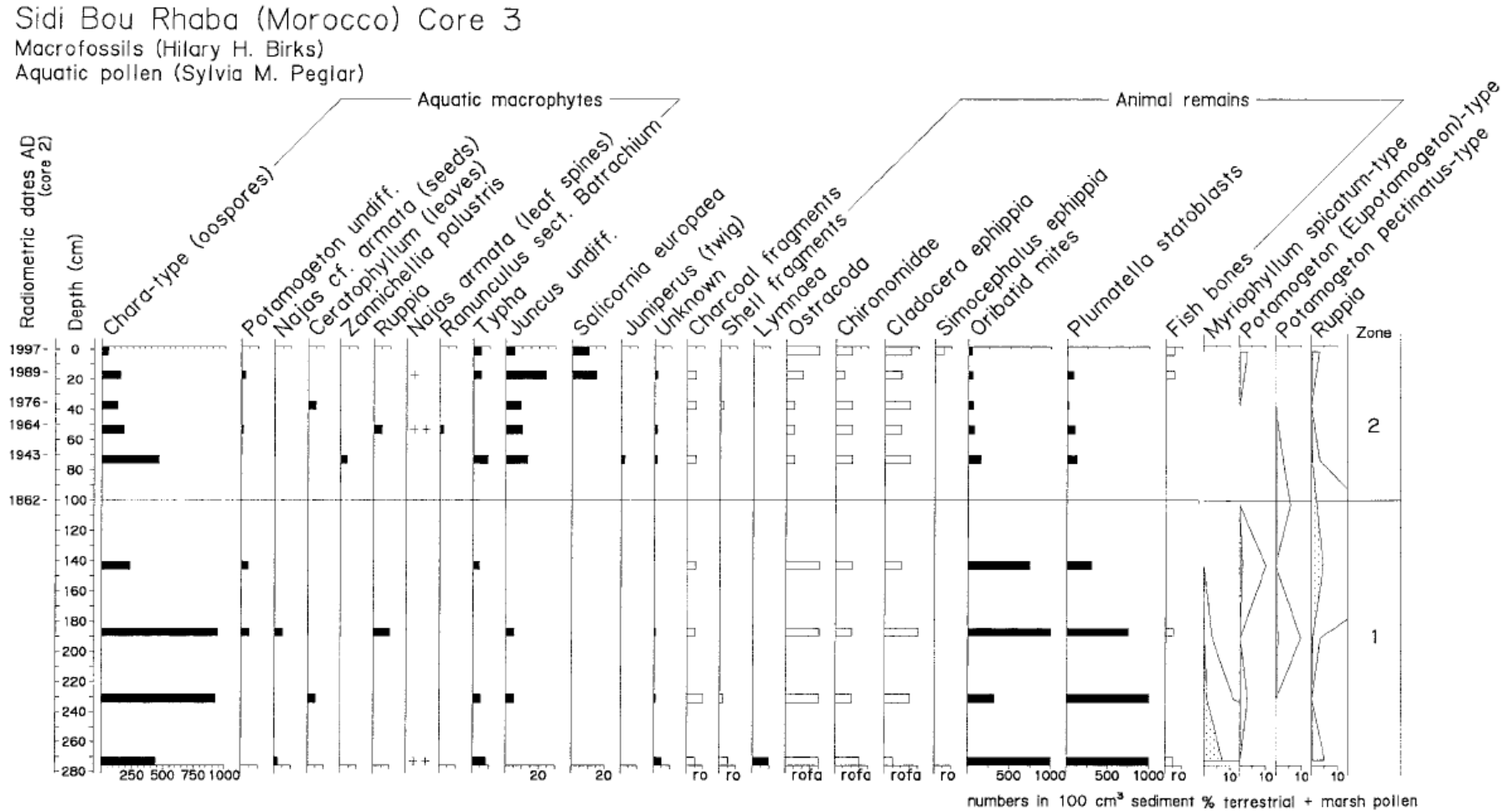


Figure 1. Stratigraphic diagram of plant and animal macrofossil concentrations and aquatic pollen percentages in core 3 from Sidi Bou Rhaba, Morocco. Radiometric ages are transferred from core 2 (Appleby et al., 2001). r = rare, o = occasional, f = frequent, a = abundant.

After about 1985 *Salicornia europaea* is present, suggesting that the water had become saline enough to support this species on summer-exposed shore mud. A general trend of increasing salinity is also detected in the detailed fossil invertebrate and diatom stratigraphies (Ramdani et al., 2001b; Flower et al., 2001). The sedimentation rate increased markedly since 1930 to about 1.4 cm yr^{-1} in 1960s and 1.7 cm yr^{-1} at the present (Appleby et al., 2001). The lake is rapidly filling in and shrinking, especially during summer drought.

Merja Zerga (Morocco) 34º17'N, 6º13'E

The 28 cm long core from Merja Zerga (ZERG-2) (Figure 2) extends back to about 1950. The basal sample is firm, shell-rich marine clay with > 20% CaCO3. The abundant molluscs (Figure 2) are typical lagoon species, except for one shell of *Melanopsis praemorsa* that is characteristic of fresh or mildly saline water with high conductivity (Brown, 1994). This could have been deposited by an inflowing river. *Ruppia* and a charophyte (probably *Lamprothamnium*) formed weed-beds near the coring site. The coring site is too far from the shore (Ramdani et al., 2001a) to estimate the extent of littoral vegetation (macrofossils of *Scirpus maritimus*-type only, and low amounts of *Phragmites*-type pollen) and salt-marshes (high Chenopodiaceae pollen percentages (Peglar et al., 2001)).

After its construction in 1953 the Canal du Nador channelled fresh water to the southwest part of the lagoon (Ramdani et al., 2001a). Shells of lagoon molluscs became rarer in zone 2, CaCO3 dropped to ca. 5%, and the increased mineral residue from the silt and clay brought in by the canal contained elevated amounts of zinc (Birks et al., 2000). The lagoon remained tidal and saline, in spite of the admixture of fresh water during the winter, as shown by the continued abundance of *Ruppia* with *Potamogeton* (*pectinatus*), *Najas marina*, *Enteromorpha*, and the continuous presence of *Zostera* (probably *Z. noltii*), an obligate marine genus. All these taxa occur in the lagoon today. *Ranunculus* sect. *Batrachium* occurred consistently, perhaps a brackish-water species growing near the inflow. Terrestrial taxa, mostly weedy species, were brought in by the canal, and the freshwater invertebrates may also have arrived in this way. *Scirpus maritimus* and *Phragmites* at the shore were joined by *Juncus maritimus* and *Salicornia europaea*, suggesting the expansion of salt-marsh on the accumulating fine sediment delivered by the Canal. The Gramineae seeds may be *Phragmites*, but they may also come from marine grasses, such as *Aeluropus littoralis* that grows in clumps in the lagoon today. The Eupotamogeton pollen could derive from *Triglochin maritima* in the salt-marshes. There was no detectable impact of the severe drought of 1980–1985, as sea level maintained the lagoon.

Figure 2 shows a large change since 1985 (zone 3). The *Ruppia* beds with *Chara*-type, *Potamogeton*, and *Zostera* and the salt-marsh taxa declined near the coring site. Molluscs and other invertebrates were much reduced. Loss-on-ignition demonstrates increased organic content, and zinc values increased further (Birks et al., 2000). The diatom record (Flower et al., 2001) indicates siltation by finer sediment, with fewer epiphytic and more epipelic forms, and a rise in salinity, probably caused by reduced fresh-water inflow from the Canal du Nador. No major external influence on the lagoon is recorded at this time (Ramdani et al., 2001a) and the changes may result from local shifting of the canal channel that altered the local environment, and perhaps also from raised residual fertiliser, nutrient, and pesticide loads in the canal water resulting from continued intensification of agriculture (Peglar et al., 2001) and local population increase (Ramdani et al., 2001a). Several cores from different parts of the lagoon are needed to track changes in vegetation distribution, such as the extent of macrophyte beds and salt-marsh. The lagoon itself seems to be in a state of sustainable equilibrium with the present level of human impact but the marginal marsh vegetation is currently being degraded by heavy grazing and the fresh-water table has been lowered by increasing water withdrawal for agriculture (Ramdani et al., 2001a).

Merja Bokka (Morocco) 34º25'N, 6º12'E

Merja Bokka on the Sebou River floodplain was supplied by the tributary Tiflet River (Ramdani et al., 2001a). The available radiometric chronology (Appleby et al., 2001) gives a sedimentation rate of ca. 0.3 cm yr−1 until a marked and maintained increase after 1988. However, the timescale covers only the top 16 cm of the 110 cm BOKK-2 core that was investigated for pollen and macrofossils (Figure 3). LOI shows a fairly constant 10–15% organic matter, but CaCO3 percentages rise sharply from 10–15% to ca. 25% at the start of zone 2 (Birks et al., 2000), reflecting the high concentration of molluscs and ostracods in this zone (Figure 3b).

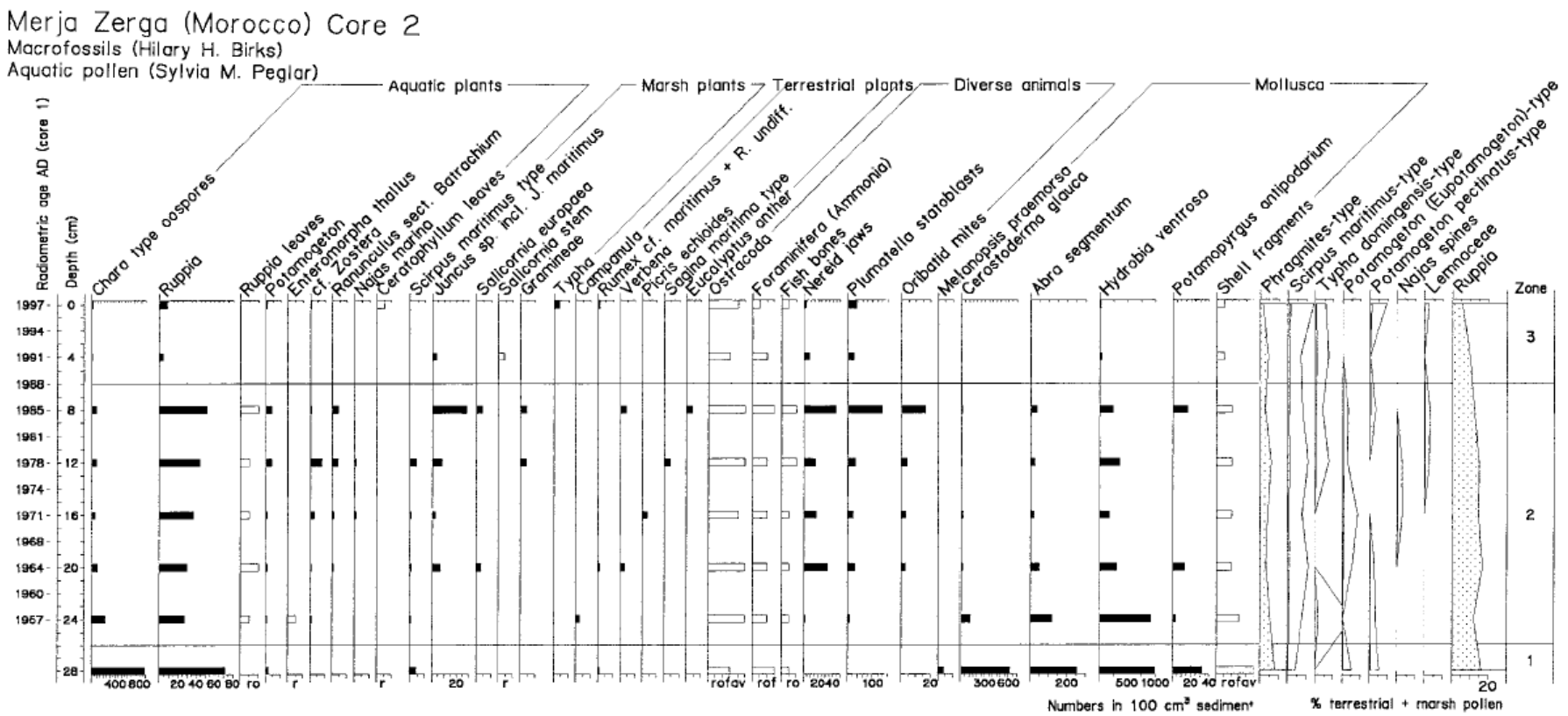


Figure 2. Stratigraphic diagram of plant and animal macrofossil concentrations and aquatic pollen percentages in core 2 from Merja Zerga, Morocco. Radiometric ages are transferred from core 1 (Appleby et al., 2001). r = rare, o = occasional, f = frequent, a = abundant, v = very abundant.

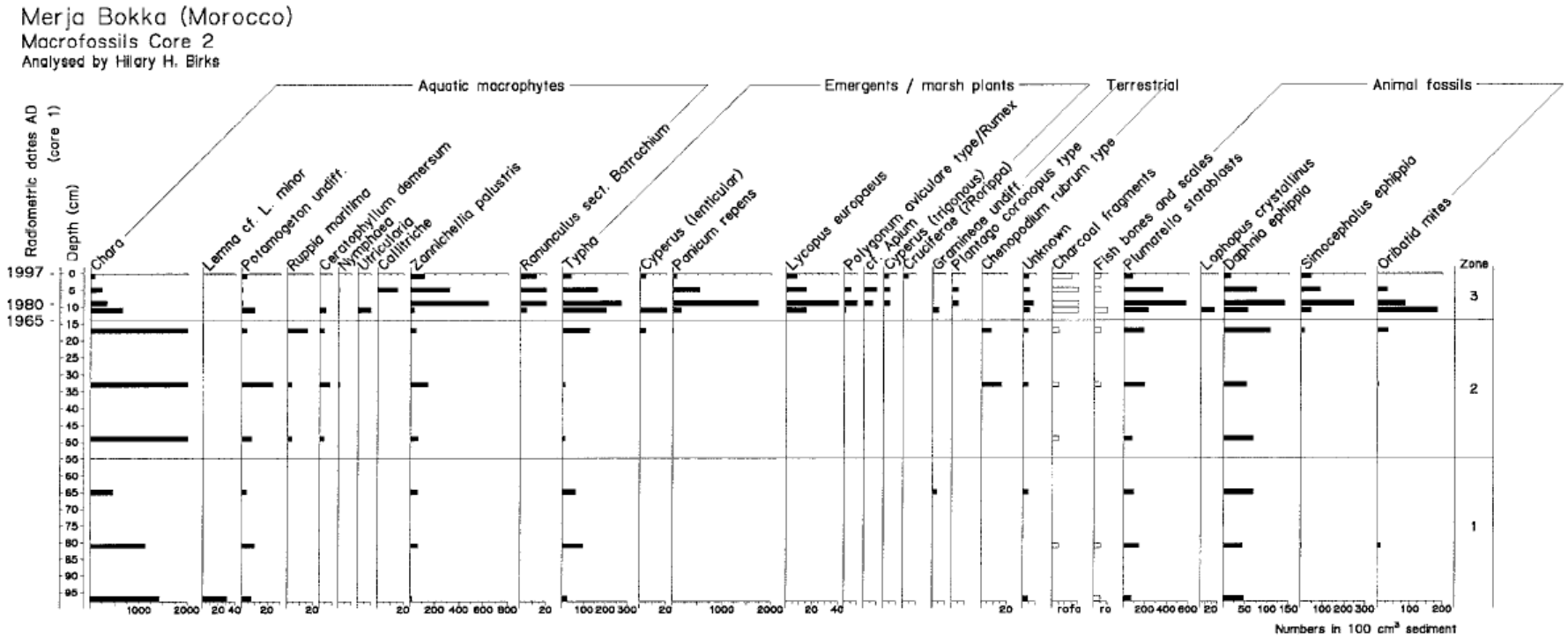


Figure 3. Biostratigraphy of core 2 from Merja Bokka, Morocco. Radiometric ages are transferred from core 1 (Appleby et al., 2001). (a) Plant and animal macrofossil concentrations. (b) Mollusca concentrations, Ostracoda, and aquatic pollen percentages. The pollen analyses extended 13 cm below the other analyses. r = rare, o = occasional, f = frequent, a = abundant.

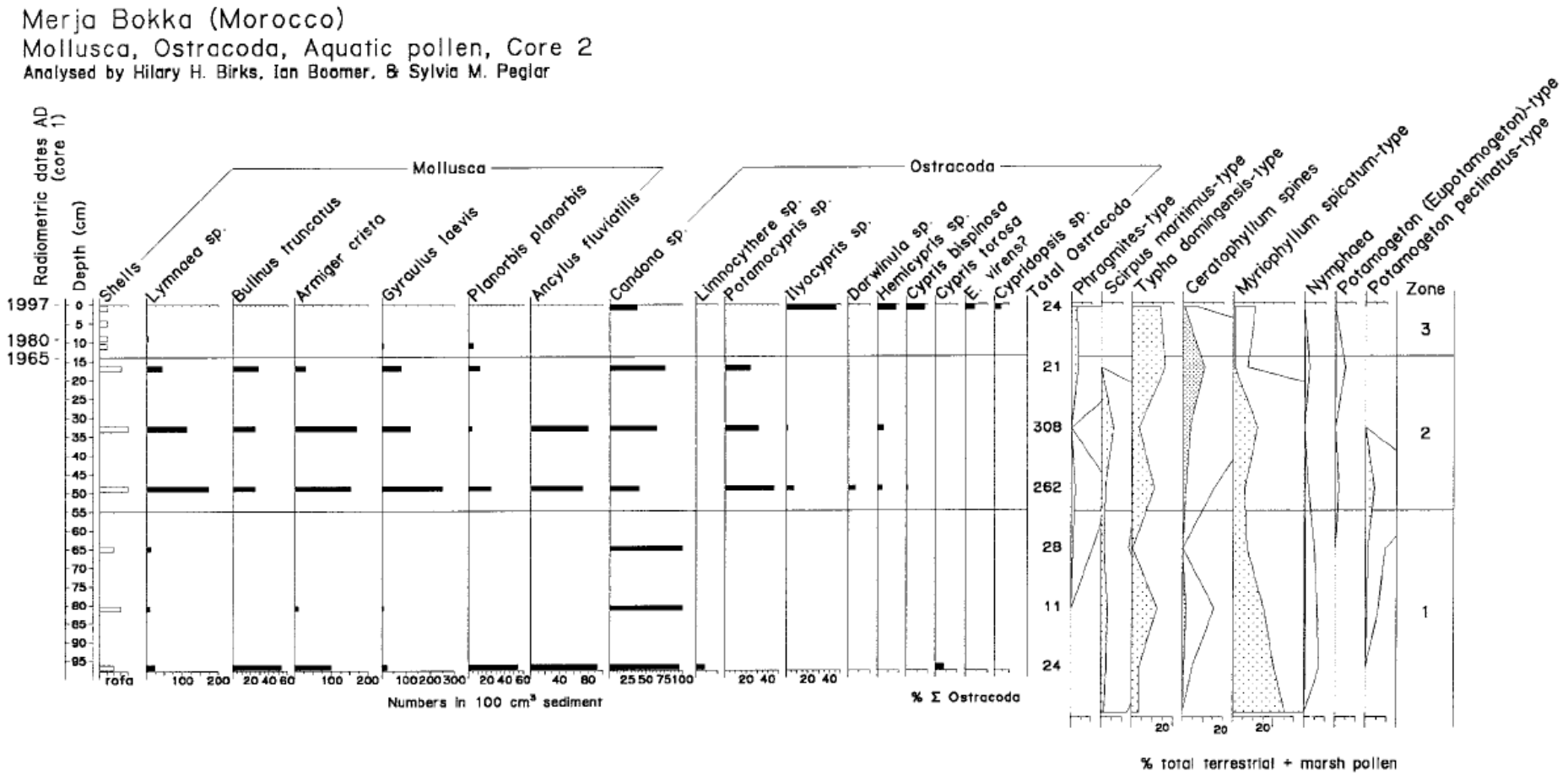


Figure 3. Continued.

The basal macrophyte assemblage of *Lemna*, *Chara*, *Potamogeton*, and *Myriophyllum spicatum* (pollen), is typical of clear fresh-water with moderately high conductivity and nutrients. The associated molluscs are characteristic of nutrient-rich ponds with calcareous water and dense aquatic vegetation (Brown, 1994). *Bulinus truncatus* is an opportunist that can tolerate desiccation but not turbidity, whereas *Lymnaea* is found only in permanent water. *Ancylus fluviatilis* is typical of streams but can also occur in lakes. Ostracods are few, mostly *Candona*, a genus typical of fresh, oligohaline water. During zone 1 *Lemna* and *Myriophyllum* (pollen) declined and *Zannichellia* increased. Molluscs became rare or absent and ostracods remained rare. At the same time the increase in the number of *Typha* fruits and pollen of *T. domingensis*type (includes *T. angustifolia*) suggests that *Typha*dominated marsh expanded towards the coring site, perhaps as a result of lower water level.

In zone 2, *Chara* and *Potamogeton*, (*P. pectinatus*type pollen) increased, *Ruppia* and *Ceratophyllum* appeared, and *Zannichellia* persisted. These aquatics tolerate high carbonate-dominated conductivity, and *Ceratophyllum*flourishes in high nutrient levels. There were dramatic increases in all molluscan taxa and ostracods. *Potamocypris* that became co-dominant with *Candona* and small percentages of other taxa, are all characteristic of fresh-water. As a result, %CaCO3 increased in the sediment, partly consisting of marl as well as shells. There is no biological evidence for increased salinity. *Bulinus truncatus* is intolerant of very high Cl^- and other electrolytes (Brown, 1994) and other aquatic animals such as *Plumatella* and *Daphnia* remained common, suggesting that salinity was low. The cause of this change could lie in water withdrawal for agriculture that was intensified from the 1920s (Ramdani et al., 2001a), resulting in concentration of CO_3^{--} by evaporation and marl production in the lake. Fluctuating water levels are suggested by the decline in *Typha* and the occurrence of *Chenopodium rubrum* seeds, a species characteristic of lake draw-down and exposed shore mud (Watts & Bright, 1968).

At 14–10 cm, 1965–1980, the lake changed dramatically. *Chara*, *Ruppia*, and *Myriophyllum* were replaced by a huge increase in *Zannichellia*, together with *Ranunculus* sect. *Batrachium*. Molluscs almost disappeared, although other aquatic animals characteristic of temporary shallow water such as *Plumatella*, *Daphnia*, *Simocephalus*, and oribatid mites increased (Figure 3a) (Ramdani et al., 2001b). Ostracod abundance decreased and *Ilyocypris* replaced *Potamocypris*. These changes suggest that the lake became shallow and disturbed, and the diatoms suggest the water became somewhatmore saline (Flower et al., 2001). The reduction in organic matter and %CaCO3, the increased proportion of mineral residue containing an increased amount of Zn (Birks et al., 2000), the rapidly increasing sedimentation rate (Appleby et al., 2001), and changes in magnetic susceptibility (Flower et al., 2001) all suggest a large input of minerogenic sediment (soil).

There were equally dramatic changes in the marginal vegetation. *Typha* increased enormously and was joined by large amounts of *Panicum repens* and *Lycopus europaeus*, together with weedy species characteristic of damp ground (Figure 3a; Peglar et al., 2001). Charcoal fragments became abundant, and the sediment is hard and red-coloured in the top 10 cm. These changes suggest that the lake was becoming very shallow. In April 1997 its recorded depth was ca. 20 cm with turbid water, and *Panicum* grew scattered across the lake (Ramdani et al., 2001a). Water supply was being reduced and the effect was exacerbated in drier years. The lake was recorded as virtually dry after the prolonged drought of 1981–1985, but refilled by 1987 (Ramdani et al., 2001a). Intensified cultivation within the wetland reed-swamp resulted in eroded soil entering the lake.

Merja Bokka and its associated luxurious wetlands used to support a high biodiversity (Ramdani et al., 2001a). The original lake level is marked by a raised shore-line. The lake responded to both natural and artificial changes in water level by maintaining a balance between reed-swamp and aquatic vegetation and their associated fauna. However, increasing disturbance and drainage control of the catchment marshes by mechanisation (Ramdani et al., 2001a), caused the lake to become increasingly shallow. Winter flooding by the rivers Sebou and Beht was reduced by drainage networks since 1953. The R. Tiflet was diverted permanently in 1998 and, deprived of its inflow, the lake became permanently dry and was ploughed in June 1998.

The biota was interesting biogeographically, containing several species that are rare in N. Africa but more typical of Europe. It was one of two Moroccan localities for *Nymphaea alba* (Fennane et al., 1999), and pollen records its presence at least 100 years ago. Two seed records confirmed its local presence up to 1990 (5 cm). The gastropods *Planorbis planorbis* and *Gyraulus laevis* are scarce in N. Africa, but have widespread European distributions (Brown, 1994).

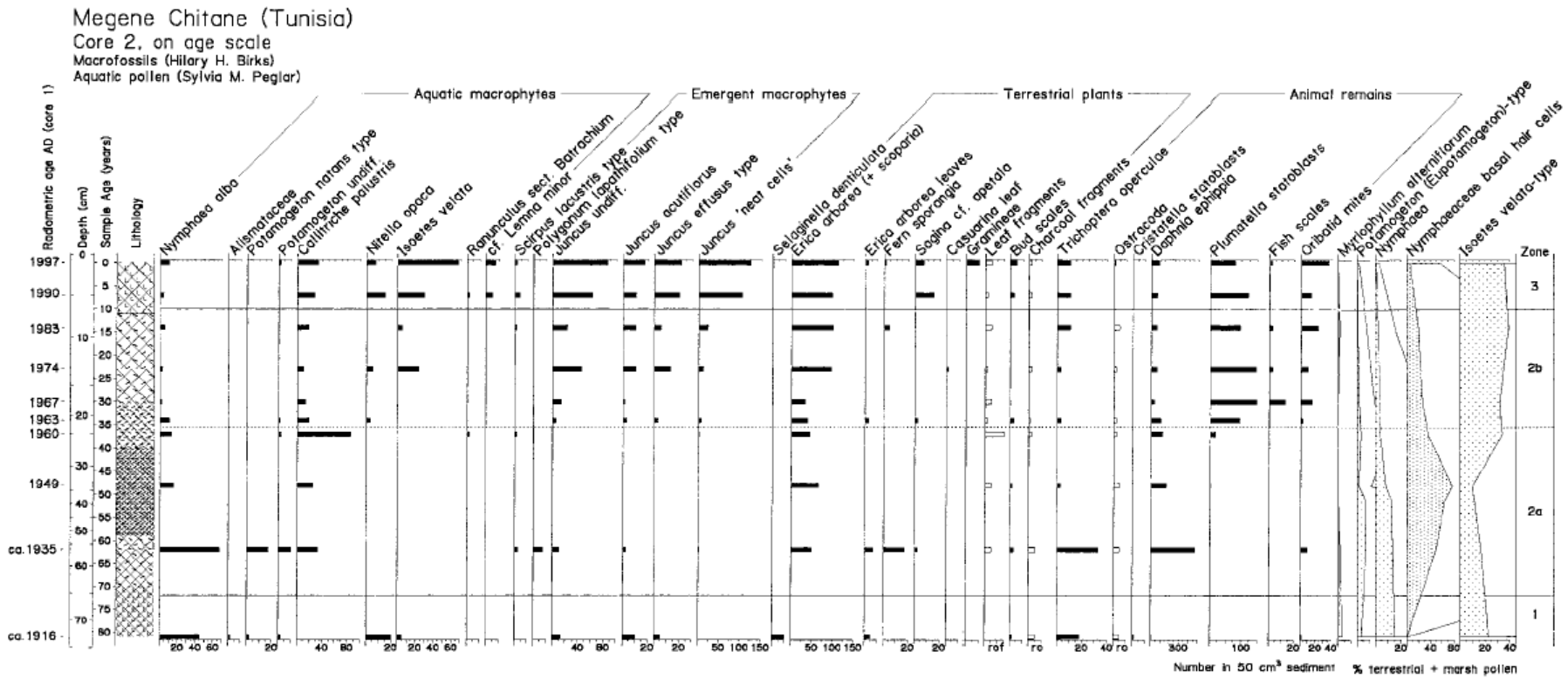


Figure 4. Stratigraphic diagram of plant and animal macrofossil concentrations and aquatic pollen percentages in core 2 from Megene Chitane, Tunisia. The radiometric ages from core 1 (Appleby et al., 2001) have been used to construct the diagram on an age scale. In the representation of the lithology, short slanting dashes are coarse and fibrous detritus, cross hatching is lacustrine mud, and 'L' pattern is minerogenic material (silt and sand). r = rare, o = occasional, f = frequent.

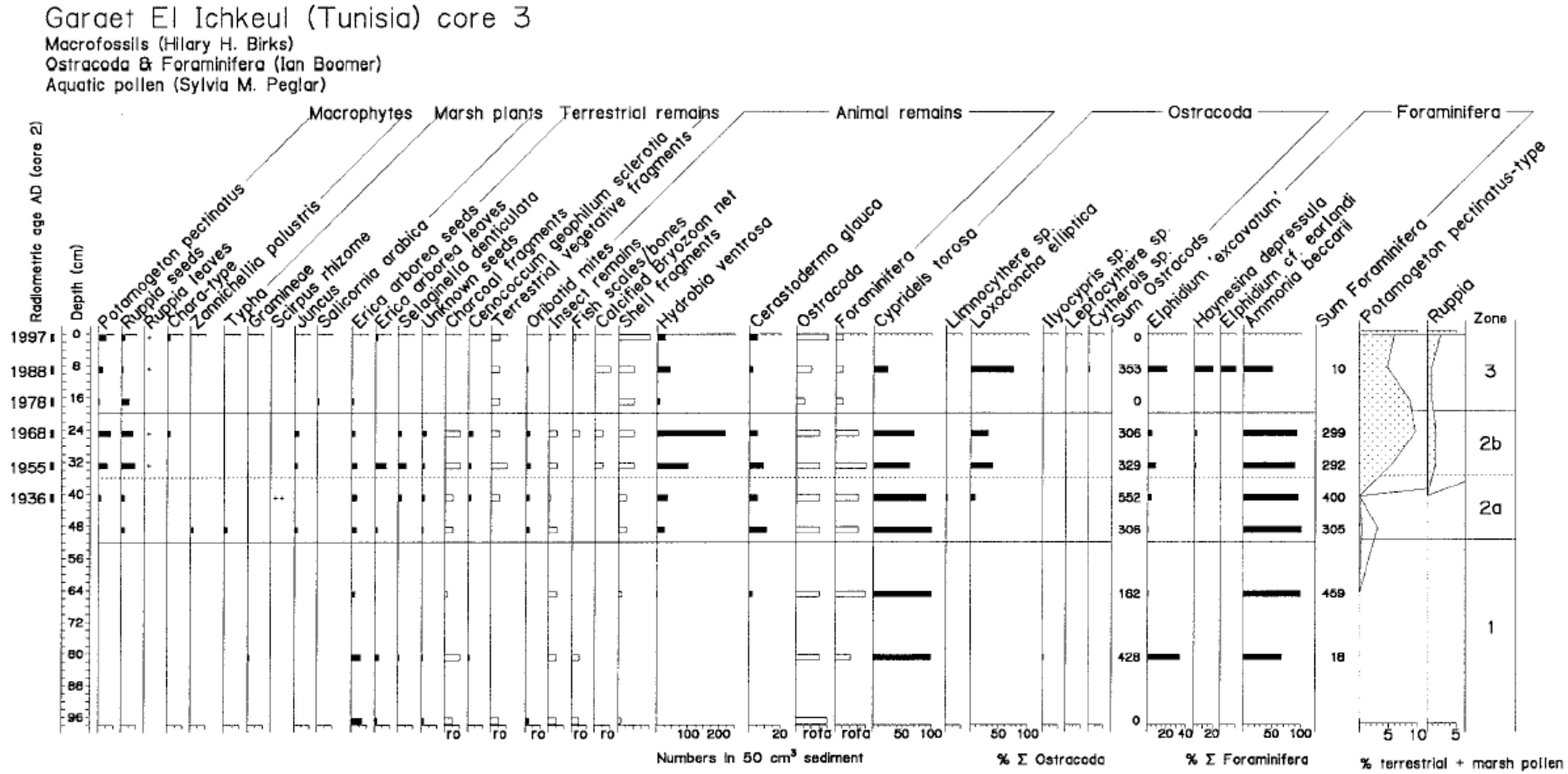


Figure 5. Stratigraphic diagram of plant and animal macrofossil concentrations, Ostracoda and Foraminifera percentages, and aquatic pollen percentages in core 3 from Garaet El Ichkeul, Tunisia. Radiometric ages are transferred from core 2 (Appleby et al., 2001). r = rare, o = occasional, f = frequent, a = abundant.

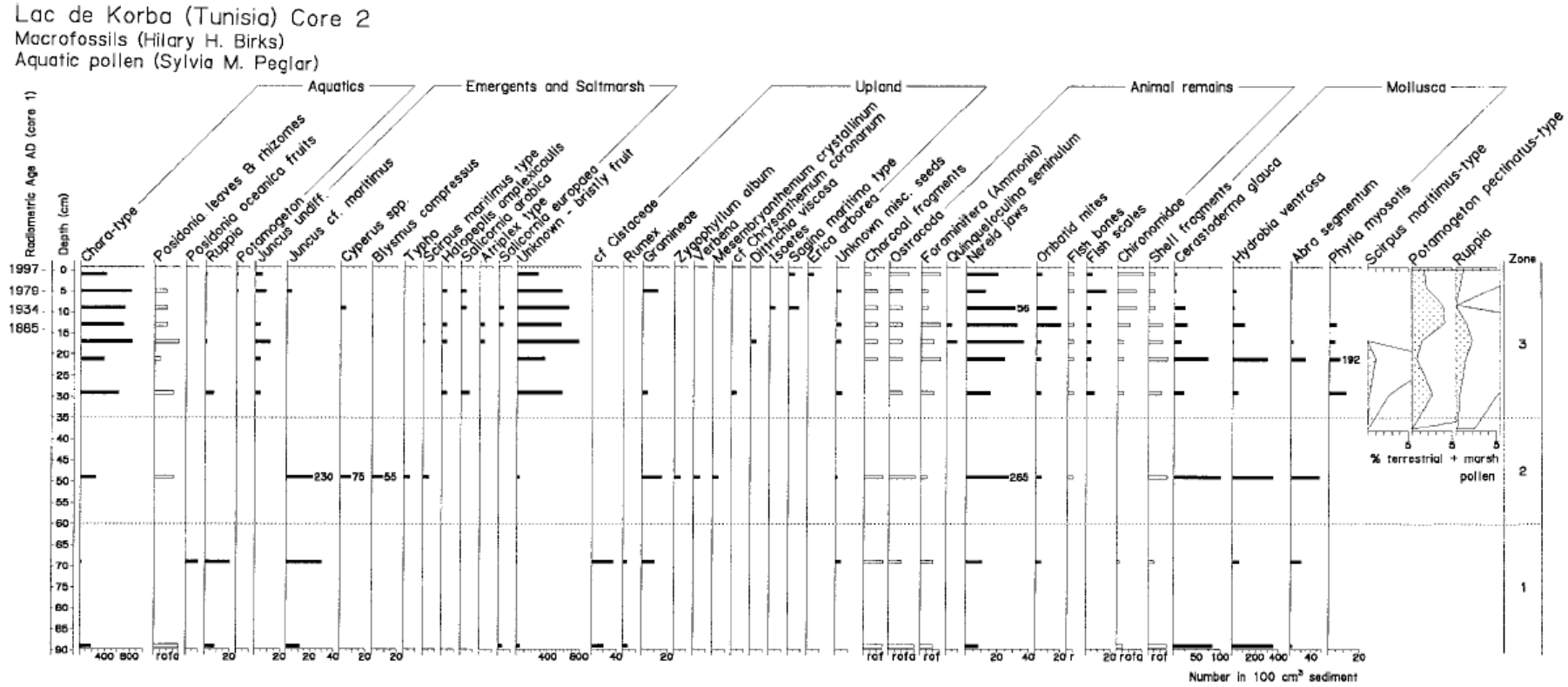


Figure 6. Stratigraphic diagram of plant and animal macrofossil concentrations and aquatic pollen percentages in core 2 from Lac de Korba, Tunisia. Radiometric ages are transferred from core 1 (Appleby et al., 2001). r = rare, o = occasional, f = frequent, a = abundant.

Megene Chitane (Tunisia) 37°11'N, 9°10'E

This is the only CASSARINA lake with dilute water and a low pH (Kraïem & Ben Hamza, 2000; Fathi et al., 2001). As a consequence its flora and fauna are quite distinct. It is an important site for the occurrence of very rare species of Cladocera (Ramdani et al., 2001c), the water lily *Nymphaea alba*, and the only N. African known occurrence of *Nitella opaca* (M. Ramdani, pers. comm.).

Radiometric dating of core SHET-1 shows that 80 cm have accumulated since the early 1900s (Figure 4). The sedimentation rate was highly variable, with very fast rates between 1944–1949 (48–33 cm) and increased rates between 1962–1965 (22–18 cm) (Appleby et al., 2001). Therefore the macrofossil diagram (Figure 4) has been plotted on an age scale to give a better impression of the rates of change at the site. The rapid sedimentation periods correspond to dryish sediment with increased LOI and % dry weight (Birks et al., 2000) composed of many fine felted fibres. Above the fibrous sediment, lake gyttja was deposited at a slower rate and the top 10 cm is harder, lumpy, iron-rich silt.

Aquatic vegetation in the early 20th century (zone 1) was diverse, and included *Nitella opaca*, *Isoetes velata*, *Potamogeton natans*, Alismataceae (Figure 4), and *Myriophyllum alterniflorum* (pollen) that are all characteristic of rather base-poor water at around pH 6. Emergent taxa were *Juncus acuti- florus* and *J. effusus*-type (Figure 4) with *Typha* and Gramineae (pollen; Peglar et al., 2001). *Nymphaea alba* was introduced to Megene Chitane (Kraïem & Ben Hamza, 2000).

Zone 2a started in the 1930s and contains the period of rapid sedimentation. Neither the macrofossil nor the pollen diagram indicate from what plant the fibrous material originated, so it must produce little of either that is preserved. A possible candidate is the aquatic form of *Juncus bulbosus* that can form dense mats in acid-water lakes in Europe, and rarely flowers or produces seeds. The lake did not dry up during this period, as *Nymphaea*, *P. natans*, *Callitriche*, and aquatic animals remained common (Figure 4), Cladocera and chironomids were plentiful (Ramdani et al., 2001b), and the diatom assemblage was characteristic of clear oligotrophic water (Flower et al., 2001). However, *Nitella* and *Isoetes* disappeared from the record, perhaps succumbing to competition from the fibre-forming plant. The fibrous material is unlikely to be catchment derived (e.g. peat inwash following disturbance of the peat-bog upstream) because the record of terrestrial macrofossils (Figure 4) and pollen (Peglar et al., 2001) hardly change. However, *Erica arborea* seeds became frequent, perhaps reflecting secondary growth after burning and/or utilisation of the catchment vegetation. Severe regional fires occurred during World War 2 and again in 1957 (Kraïem & Ben Hamza, 2000). The influx of ash and nutrients could have stimulated the growth of *Juncus bulbosus*.

Fibrous material gradually decreased in zone 2b, *Nitella* and *Isoetes* returned to the aquatic assemblage, and *Callitriche* was well represented. *Nymphaea* was still present but in lower amounts (Figure 4). Amongst the fauna, *Plumatella* and oribatid mites expanded markedly, but *Daphnia* declined, perhaps due to predation by fish, mostly carp, that were introduced in the 1960s and whose scales are present in the sediments. In shallow water *Juncus* spp. expanded.

The change to zone 3 is marked by increases in *Isoetes velata* megaspores, *Nitella*, and *Callitriche*, and the expansion of *Lemna minor*. Beginning in the 1980s, the sediment changed to a consistency suggesting periodic exposure and drying up in summer. This may be due to hot dry summers, but it was undoubtedly exacerbated by the increased rate of water withdrawal for catchment cultivation. *Juncus* spp. increased markedly, particularly an unidentified taxon (*Juncus* 'neat cells') that might well be *J. heterophyllus* that grows in the lake today (Ramdani et al., 2001a). This species and *Isoetes velata* grow especially well in shallow water that tends to dry up in summer. *Callitriche* too can thrive on damp mud, or survive drought as seeds. The diatom assemblage contains taxa characteristic of exposed mud, suggesting fluctuating water levels (Flower et al., 2001). However, there was enough permanent water to allow the persistence of *Nymphaea* and *Potamogeton* and aquatic animals (Figure 4; Ramdani et al., 2001b). The occurrence of *Lemna minor* suggests increased nutrient levels, probably from fertiliser residues entering the lake, or possibly also during early winter when exposed sediments were inundated once more (M. Kraïem, pers. comm.). The zooplankton and diatom changes also reflect recent eutrophication (Ramdani et al., 2001b; Flower et al., 2001).

Over the last 100 years the ecosystem of Megene Chitane has experienced rapid deposition of fibrous plant matter, but it recovered to a state similar to its previous condition in 1900. However, as the lake became shallower over the last 20 years, due partly to sediment accumulation and partly to lowering of the water level, *Juncus* species and other emergents recorded in the present vegetation (Ramdani et al., 2001a) such as *Typha angustifolia*, *Scirpus lacustris*, *Aeluropus littoralis* and

Panicum repens that are not represented by macrofossils and poorly by pollen, expanded, together with species tolerant of seasonal dryness. Although *Nitella opaca* was the first record for N. Africa, it has not been found living during the recent monitoring (Ramdani et al., 2001a) and may already be extinct. This unique lake is under severe threat. The springs in the local aquifer are drying up and all the water is being taken for irrigation (Ramdani et al., 2001a). If the water supply is restored, the ecosystem will be sustained, but no lake ecosystem is resilient enough to withstand drying up. At present, the lake and its immediate surrounds are a nature reserve, but unless the water removal occurring outside the reserve is controlled, the lake will be destroyed in a few years.

Garaet El Ichkeul (Tunisia) 37º02'N, 9º48'E

The geography, vegetation, and hydrology of Garaet El Ichkeul in the late 1980s and its recent palaeolimnology were studied by Stevenson & Battarbee (1991). Hollis (1986) predicted that the unique reedmarsh ecosystem, so important for over-wintering birds, would be threatened by withdrawal of winter fresh-water inflow by the planned building of barrages across the main inflow rivers The threat is now reality, and the formerly extensive *Scirpus/Phragmites* marshes that relied on the winter-fresh summer-saline water regime have now all died, and the bare mud is being colonised by salt-marsh species, particularly *Sarcocornia fruticosa* (Ramdani et al., 2001a). It is still a RAMSAR site but its World Heritage Site designation is uncertain.

Our short sediment core (ICHK-3) (Figure 5) is ca. 2 km from the inflow of the Sedjenane River (Ramdani et al., 2001a). The radiometric age scale from adjacent core ICHK-2 (Appleby et al., 2001) indicates that the first sample in zone 2a at 48–50 cm was deposited ca. 1920 and the start of zone 2 at 52 cm was deposited ca. 1890. The sedimentation rates in our cores are about double those in cores 2 and 8 of Stevenson& Battarbee (1991), and in contrast, are gradually increasing, presumably due to their proximity to the Sedjenane River that has been an increasing source of sediment to the west end of the lake.

The macrofossil, Ostracoda, and Foraminifera stratigraphies are shown in Figure 5, and the pollen data are presented by Peglar et al. (2001). Zone 1 contains low amounts of *Typha*, *Scirpus*, and *Alisma*-type pollen but no macrofossil records of aquatic and marsh plants, suggesting that these were sparse before ca. 1890. Mollusca were rare, but ostracods were abundant throughout, dominated by euryhaline *Cyprideis torosa*. The presence of oligohaline *Ilyocypris* may indicate relatively fresh conditions early in the sequence. Increasing Foraminifera in zone 2, dominated by *Ammonia beccarii*, a widespread taxon in lagoons of 10–40_ salinity, suggest increasing salinity levels (see also Stevenson & Battarbee, 1991).

Ichkeul is linked to the sea through the Oued Tinja and Lac de Bizerte (Hollis, 1992; Ramdani et al., 2001a). Widening the sea connection as the Bizerte Ship Canal in 1895 facilitated the inflow of saline water into Ichkeul during summer, when evaporation exceeded fresh-water inflow to the lake, and the annual salinity cycle was enhanced (Stevenson & Battarbee, 1991). The biotic effect in zone 2a was the development of *Potamogeton* and *Ruppia* vegetation, and there is an indication of reed-marsh development of *Typha*, *Scirpus*, and *Juncus* (Figure 5), a development also noted by Stevenson & Battarbee (1991). However, our core is probably too far from the shore to reflect the local developments fully. Lagoonal molluscs, *Hydrobia* and *Cerastoderma*, expanded but their shells are small and in relatively low concentrations, insufficient to affect the %CaCO3 in the sediment. Conditions at the west end of the lake were suboptimal for the molluscs, possibly because the salinity here was too low or fluctuated too much, whereas shell layers were recorded in the sediments elsewhere (Stevenson & Battarbee, 1991).

Between 1950–1970s (zone 2b; Figure 5) *Hydrobia* numbers increased, and *Cyprideis torosa* was joined by *Loxoconcha elliptica*, an ostracod typical of brackish water estuaries with 10–20 salinity. *Ammonia beccarii*, the most abundant foram, was joined by *Elphidium 'excavatum'* and *Haynesina depressula*, characteristic of inter-tidal mud flats and sublittoral marine and estuarine habitats. The increases in *Potamogeton* and *Ruppia* seeds and pollen suggest the expansion of aquatic weed-beds in the western part of the lake. Between 1950 and ca. 1975 the ecological conditions of the lake were probably optimal as a bird habitat as the reed-marshes and weed-beds were at their greatest development (Hollis, 1986).

During the next 20 years the inflowing rivers were successively canalised and dammed for irrigation purposes (Kraïem & Ben Hamza, 2000). Eventually, the winter fresh-water supply from

precipitation and local run-off was not sufficient to maintain the annual salinity cycle or winter flooding of the marshes. In zones 1 and 2 terrestrial macrofossils were consistently present, probably brought in via the rivers. During zone 3 they were reduced as the supply source was cut off. Monitoring shows that the lake was saline all year round after the early 1980s (Hollis, 1992) although recent measurements suggest a small, very recent salinity reduction (Fathi et al., 2001). The effects of the salinity increase are seen in the diagram. The *Potamogeton* and *Ruppia* weed-bedswere reduced and *Scirpus* marshes declined at the end of the 1980s. The *Phragmites* beds broke up in the early 1990s (A.C. Stevenson, pers. comm.). The expansion of salt-marsh is indicated by the occurrence of *Sarcocornia fruticosa* (= *Salicornia arabica*) that is now common around the lake. *Loxoconcha elliptica* increased relative to *Cyprideis*, and *Leptocythere* and *Cytherois* appeared, characteristic of more 'marine' conditions. Increases in *Elphidium* spp. and *Haynesina* suggest the occurrence of tidal mud-flat habitats.

The primary impacts of the human-induced salinity and flood-level changes were the reduction in reedmarsh and weed beds. Consequently, water turbidity and sediment mixing increased, as the long wind fetch across the shallow lake disturbs the unprotected surface sediments. Molluscs and macrophytes were adversely affected, and perhaps also the forams, as their total numbers decline. Disturbance and resuspension of the sediment also resulted in the large increase of indeterminable pollen and the insensitivity of the record to very recent ecosystem changes (Peglar et al., 2001; Appleby et al., 2001) (Figure 5). Recent events in the Ichkeul ecosystem demonstrate its great sensitivity to water quality changes, and how fast major ecosystem changes can occur. The reed-marshes were destroyed in < 15 years, but if winter fresh-water in- flow were to be restored, it is possible that the marshes would recover so long as a few 'parent' plants remain. The value of conserving and promoting biodiversity has to be balanced against human requirements. Although there is great concern and efforts are being made in Tunisia to conserve the wildfowl value of Ichkeul (Kraïem & Ben Hamza, 2000), the lake has now entered a phase of low biodiversity and productivity. Its value as a winter site for birds has been considerably reduced.

Lac de Korba (Tunisia) 36º46'N, 11º00'E

The sediments in this elongated hypersaline lagoon are clay-rich, with less than 5% CaCO3 except in a shell layer around 48 cm in core KORB-2 (Birks et al., 2000). The radiometric ages transferred from core KORB-1 (Appleby et al., 2001) show a slow sedimentation rate, estimating an age of ca. 1885 for 14 cm (Figure 6). The whole 90 cm core must cover several centuries.

In zone 1 (Figure 6) the recorded aquatic macrophytes are *Ruppia*, *Posidonia oceanica*, and *Chara*type, which includes *Lamprothamnium* and other species. All these taxa tolerate sea-water. High salinity is confirmed by the Mollusca and Foraminifera assemblages. The littoral salt-marsh was dominated by *Juncus maritimus* with a little *Salicornia*, perhaps indicating that the water was deeper than today. The single sample of zone 2 differs markedly from those above and below. *Ruppia* was absent and the marsh was dominated by *Juncus maritimus*, *Blysmus compressus*, and *Cyperus* spp., together with *Scirpus maritimus*. The presence of *Typha* may suggest some fresh-water influence and the Gramineae fruits may originate from *Phragmites* or other grasses of saltmarsh or sand-dune habitats likely to be growing at the lagoon. The presence of seasonally wet sandy soils is indicated by *Zygophyllum album*, *Mesembryanthemum crystalinum*, and other terrestrial taxa such as *Verbena*. The water remained saline, and lagoon molluscs and nereid jaws increased.

Zone 3 is quite uniform and different from zone 2. *Chara*-type oospores increased greatly, and *Ruppia* reappeared. *Posidonia* remained abundant, and *Potamogeton* (*pectinatus*) pollen was frequent and fruits were recorded after about 1970. Ostracods, forams, and nereid jaws maintained a steady abundance. The lagoonal molluscs increased after a phase of low abundance, and were joined by *Phytia myosotis*, a species typical of Mediterranean saline lagoons. The foram *Quinqueloculina seminulum* is also recorded, but its arrival and expansion are shown in more detail by Ramdani et al. (2001b) together with the succession of other forams, ostracods, and chironomids. The numbers of mollusc shells declined after ca. 1930, but other invertebrates maintained their populations. The *Juncus*-Cyperaceae marsh of zone 2 was replaced by a salt-marsh dominated by Chenopodiaceae with *Juncus* and *Scirpus maritimus*. The pollen record (Peglar, unpublished) adds *Triglochin maritima* (Eupotamogeton-type) and *Damasonium alisma*. In addition, the vegetation contained large amounts of a species that produced abundant small, elongated bristly fruits that defy identification. *Posidonia*

was not found in the recent sediment and was not recorded growing in the lagoon during monitoring (Ramdani et al., 2001a), although it grows in the adjacent Mediterranean.

Lac de Korba has always been saline or even hypersaline as it is today (Fathi et al., 2001). It is the only CASSARINA site that contained *Posidonia*. The vegetation changes over the last few centuries may have been caused by changes in the sedimentary environment resulting from changes in the configuration of the sand-dunes and contacts with the sea. Silt and clay deposition may have encouraged the development of the zone 2 *Juncus*-Cyperaceae marsh, and then its replacement by the Chenopodiaceae-dominated marsh that still occupies the site today. This vegetation has persisted over ca. 200 years and there is little detectable impact from the development of Korba town (Ramdani et al., 2001a). However, the raised levels of Pb (Birks et al., 2000) in the top 4 cm of sediment (ca. 1980) could indicate pollution from the town. This may be responsible for the loss of *Posidonia* and the lagoon gastropods, but the hypersalinity and O2 depletion that develop in summer (Fathi et al., 2001) may also be important factors. The effect of the modern Pb levels on the over-wintering bird populations is not known, but numbers are decreasing because of deteriorating water quality (Kraïem & Ben Hamza, 2000). Fresh-water withdrawal from the water table by wells and by damming of the inflow streams Shiba and Lebna is also a problem. Since 1986, the Lebna lagoon to the north (Kraïem & Ben Hamza, 2000) has been dry and the fresh-water water table has been generally lowered, leading to a shallower lake, shrunken in summer. In addition, the fertilizer load to the lake has increased due to the intensification of agriculture and has probably resulted in the expansion of *Enteromorpha* and *Ulva* at the expense of the natural vegetation (Ramdani et al., 2001a). The resilience of Korba is probably high, having been quite stable for ca. 300 years, but pollution, eutrophication, and reduced fresh-water supply are severe modern threats. It is to be hoped that new management plans instigated in 1993will defer some of the most serious consequences (Kraïem & Ben Hamza, 2000).

The Egyptian delta lakes

The Delta lakes are lagoons connected to the Mediterranean Sea. They are all in the same hydrological system that has suffered a rise in fresh-water table caused by increased control of the Nile flow over the last ca. 100 years that aimed to promote year-round irrigated cultivation to replace the natural seasonal cycle. The main historical events are summarised from Waterbury (1979). Major barrage and canal constructions started in the 19th century and the dams at Aswan (1902, raised in 1912 and 1933; Aswan High Dam 1964) resulted in perennial irrigation in the Delta, where inadequate drainage led to over-watering and a continuing rise in the water-table during the 20th century, the loss of Nile silt and its contained nutrients, increased soil salinisation through evaporation, and increased coastal erosion due to silt deprivation. The massive inflow of drainage water through the year has raised the lake-levels and measured lake-water salinity has steadily decreased since about 1920 (Fathi & Abdelzaher, 2000). Recently deteriorating water quality from sewage and from residues of insecticides, molluscicides, and fertilizers has led to decreased fish production. In addition, nearly half the lakes' area has been reclaimed to replace land lost to urbanisation and salinisation (Goodman & Meininger, 1989). The population of Egypt is expanding very rapidly, Delta land is becoming urbanised (Sultan et al., 1999), and more land is sought.

The year-round availability of open water in the Delta drains has allowed the spread of snails (plus the diseases they carry (Brown, 1994)) and of aggressive water plants, particularly submerged *Potamogeton pectinatus* and *Ceratophyllum demersum* and floating *Eichhornia crassipes* (Zahran & Willis, 1992). The introduced water hyacinth was recorded as abundant in the Delta lakes by 1935 (Zahran & Willis, 1992) and it now covers about 80% of all water surfaces in summer (Goodman & Meininger, 1989). Introduced floating *Azolla filiculoides* has also increased (Boulos, 1999). Reed-marsh has spread over previously exposed sand bars (Goodman & Meininger, 1989). Together with pollen evidence of historically documented tree introductions and planting (Peglar et al., 2001), these historical events have contributed towards constructing a chronology for the lake sediments, supplementing the poor radionuclide record in this region of very low rainfall (Appleby et al., 2001).

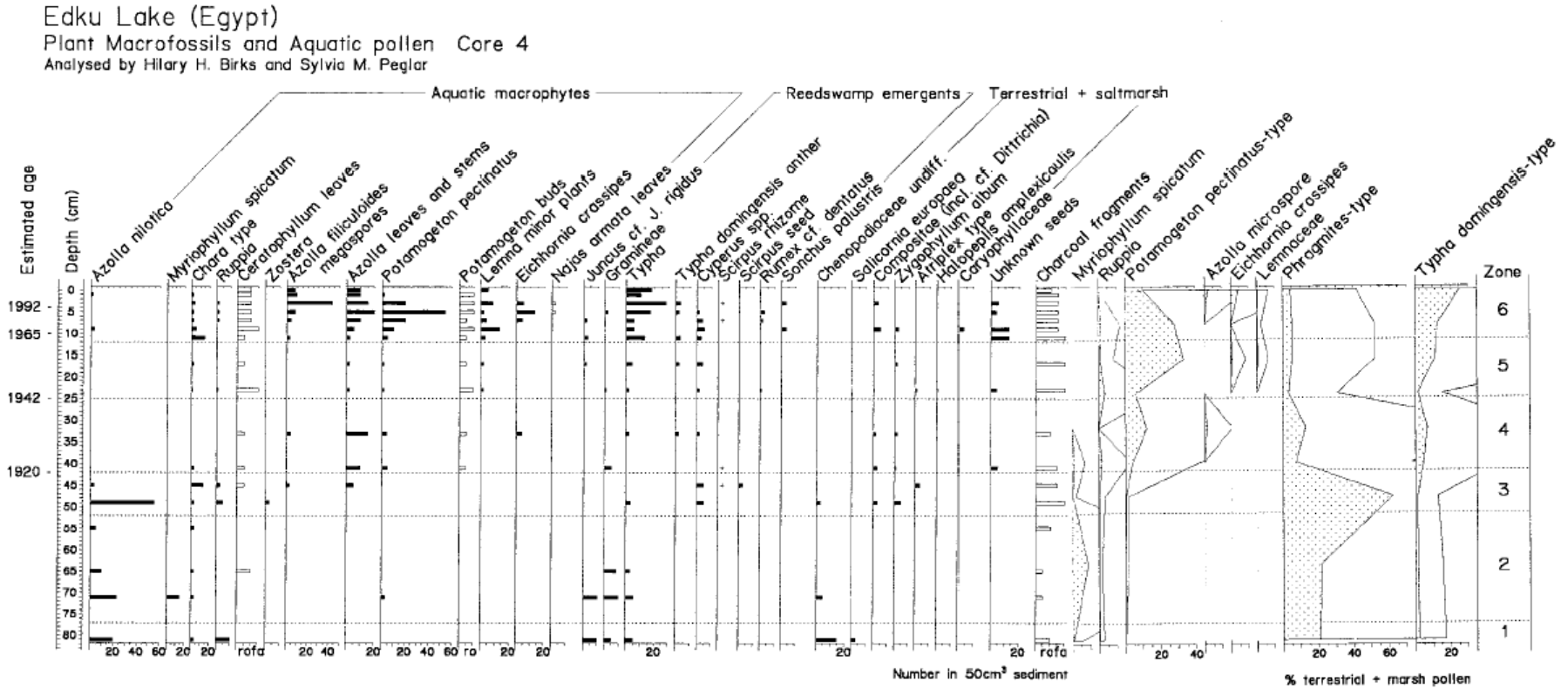
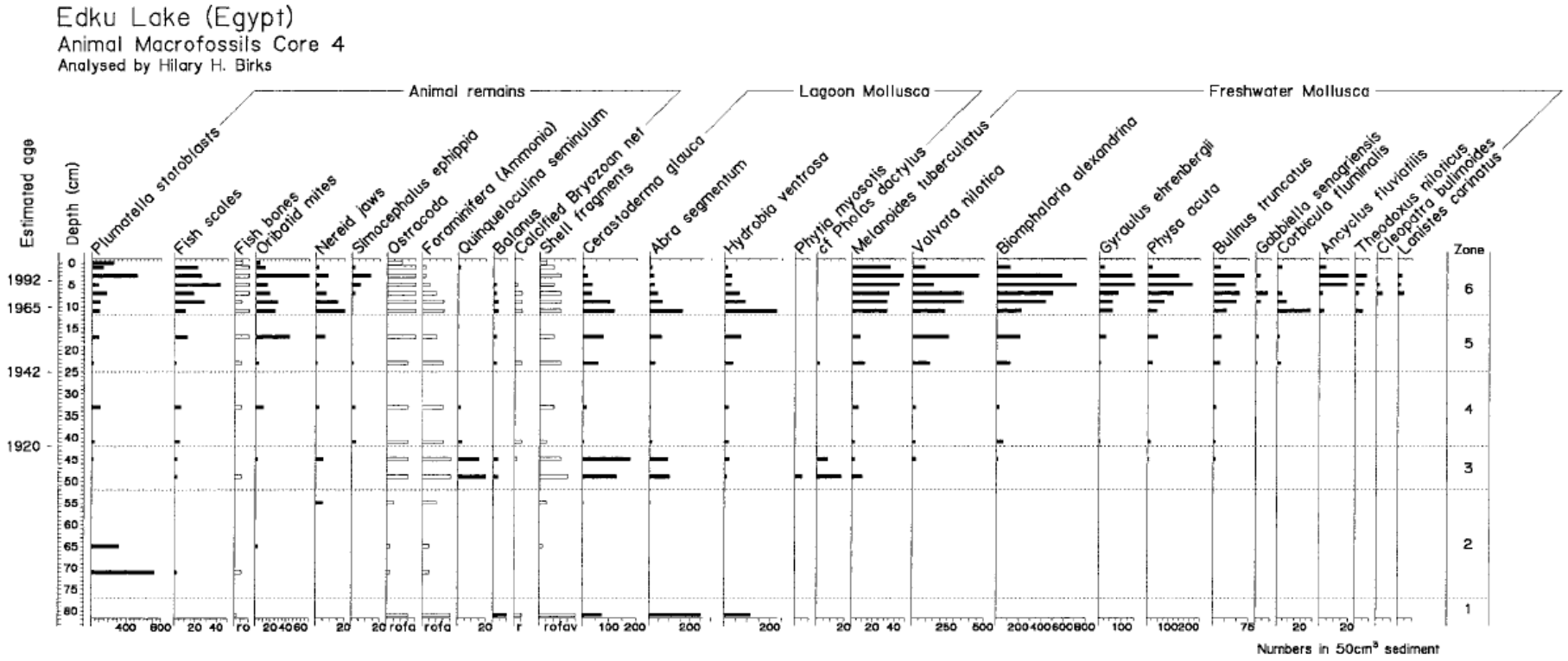


Figure 7. Biostratigraphy of core 4 from Edku Lake, Egypt. Ages are estimated from the timescale constructed by Appleby et al. (2001). (a) Plant macrofossil concentrations and aquatic pollen percentages. (b) Mollusca and other animal macrofossil concentrations. r = rare, o = occasional, f = frequent, a = abundant, v = very abundant.



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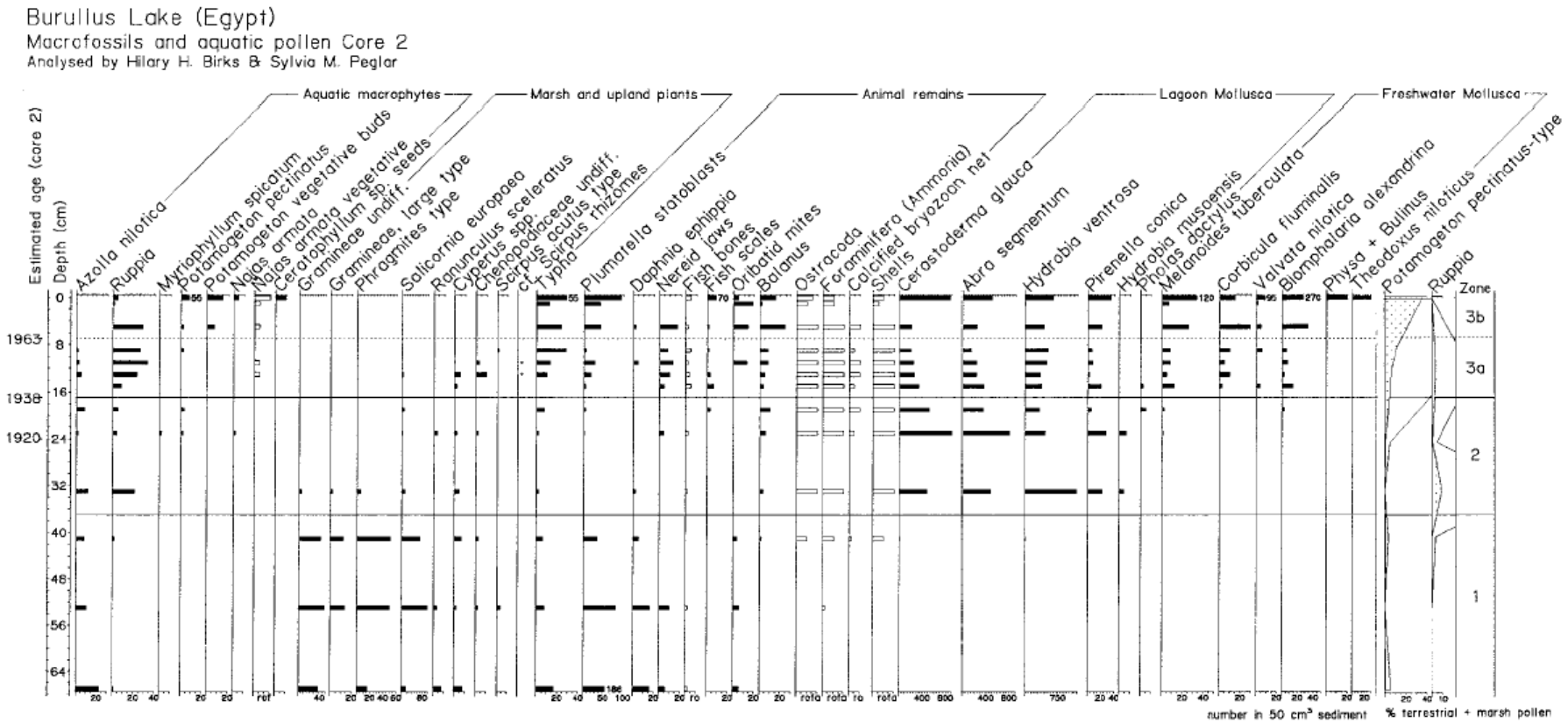

Figure 8. Stratigraphic diagram of plant and animal macrofossil concentrations and aquatic pollen percentages in core 2 from Burullus Lake, Egypt. Ages are estimated from the timescale constructed by Appleby et al. (2001). r = rare, o = occasional, f = frequent, a = abundant.

Edku Lake (Egypt) 31°15'N, 30°15'E

The base of core IDKU-4 (Figure 7; zone 1) was sedimented in open lagoon conditions. Lagoon molluscs, forams, and ostracods were abundant in *Ruppia* and *Chara*-type vegetation. Salt-marsh is indicated by high Chenopodiaceae pollen (Peglar et al., 2001) and seeds of Chenopodiaceae and *Salicornia europaea*, and marginal reed-marsh by *Typha*, *Phragmites* (pollen) and *Juncus* cf. *J. rigidus*. *Azolla nilotica* was common on the water. In zone 2 (Figure 7) lagoon molluscs and *Ruppia* disappeared and *Myriophyllum spicatum* (seeds and pollen), *Ceratophyllum*, and the freshwater bryozoan *Plumatella* all appeared. *Azolla nilotica* remained common. Reed-marsh was not well developed near the core-site. These changes suggest an open lake with a reduced marine influence, the water being fresh to mildly brackish with few macrophytes. Chenopodiaceae (pollen) were still common on sandy shores (Peglar et al., 2001).

In zone 3 *Chara*-type and *Ruppia* increased and the obligate marine *Zostera* occurred. *Azolla nilotica* reached its maximum abundance. Reed-marsh with *Scirpus*, *Cyperus*, and *Phragmites* (pollen) spread, and the expansion of salt-marsh and sandy soil vegetation is shown by Chenopodiaceae pollen and seeds of *Atriplex*, *Zygophyllum album*, and cf. *Dittrichia* and other Compositae (Figure 7a). Forams, including *Quinqueloculina seminulum*, ostracods, and the lagoon bivalves *Cerastoderma glauca* and *Abra segmentum* increased, and *Phytia myosotis* and large shells of *Pholas dactylus* were recorded (Figure 7b). Some of these shells and forams may have been brought in from the sea or redeposited from older shell deposits during storms, but it seems likely that saline influence increased markedly in the lagoon.

In zone 4 lagoon molluscs all declined rapidly and fresh-water gastropods started to appear. *Ruppia* and *Chara*-type also declined. *Azolla nilotica* is absent after ca. 1920 (zone 4). This species is extinct in Egypt, its nearest recorded occurrence being in S. Sudan (Saunders & Fowler, 1992). It was present in the Nile Delta up to ca. 600 AD (Leroy, 1992) and the short CASSARINA cores from all the Delta lakes record its more recent presence. The reasons for its extinction are unclear, as it seems to have tolerated a considerable range of salinity in the recent past. It may suffer from eutrophication or pollution, in contrast to the invasive *A. filiculoides*. The macrophyte vegetation of zone 4 consisted of *Potamogeton pectinatus* and *Ceratophyllum* and quantities of the introduced *Azolla filiculoides*. A seed of *Eichhornia* was recorded. Peglar et al. (2001) record pollen of *Casuarina* and *Eucalyptus* at ca. 40 cm, coincident with the start of zone 4 (Figure 7), suggesting an age of ca. 1920 when these trees were first widely planted (Appleby et al., 2001). This interpretation is supported by the presence of *Eichhornia*. It is not known when *Azolla filiculoides* was first introduced. The water during zone 4 was (perhaps periodically) brackish, as shown by the presence of forams and ostracods but conditions were no longer suitable for the lagoon bivalves, and the sediment became browner and softer.

In zone 5, in 1940s, the large increase in several fresh-water mollusc species and the addition of new species (Figure 7b) indicate increasing fresh-water in- fluence. The increases of *Ceratophyllum* and *Lemna* probably reflect increasing eutrophication (Figure 7a). *Cyperus* and *Typha* indicate the presence of reedmarsh, but *Phragmites* (pollen) declines. Lagoon molluscs increase in zone 5, perhaps indicating increased marine influence. However, many of the shells are very small and perhaps are transported or could not survive into adulthood. There may have been periodic marine influence, suggested particularly by the diatom assemblage (Flower et al., 2001), but the input of fresh-water encouraged the growth of fresh-water mollusca, at least in the drains entering the lake.

In zone 6 (ca. 1965) *Potamogeton pectinatus*, *Azolla filiculoides*, and *Lemna* expanded and *Chara*type and *Ruppia* reappeared. *Ceratophyllum* was abundant. Seeds and pollen of *Eichhornia* and leaf spines of *Najas armata* are recorded, and both species grow in the lake today. *Azolla filiculoides* was recorded as covering Edku Lake in 1992, when it was responsible for adding tonnes of nitrogen to the water by nitrogen fixation (El-Shenawy, 1994). Its peak at 4 cm could correspond to this major expansion, since when it seems to have decreased. The fresh-water influence from the Aswan High Dam since 1964 has resulted in a steady decline of lagoon molluscs and forams, but has encouraged fresh-water mollusca, and several more species have appeared recently. *Ancylus fluviatilis* may have been transported from drains, but most of the other species were found alive in the lake in 1997 during monitoring. Increased productivity is reflected by the increase of other aquatic organisms, particularly *Plumatella*, *Simocephalus*, oribatid mites, and fish. Nereid jaws were common at the start of the zone, but decreased in line with the lagoon molluscs. Reduced variation in salinity is reflected in the diatom record (Flower et al., 2001). The improved representation of reed-marsh indicates its expansion

towards the core site. *Typha domingensis*was common, but *Phragmites* is surprisingly poorly represented considering its abundance in the present vegetation.

The question of redeposition of fossils should be considered. Besides bioturbation by e.g. nereid worms, chironomids, etc., punt-poling and fishing disturb the sediments. Possibly the *Azolla nilotica* megaspores and *Quinqueloculina seminulum* in zone 6 were redeposited and some of the early records of *A. filiculoides* and *Eichhornia* may result from deep mixing by punt poles. However, the stratigraphy and chronology (Appleby et al., 2001) are otherwise coherent, so redeposition is probably not a major consideration.

Burullus Lake (Egypt) 31º21' – 35'N, 30◦30' – 31º10'E

During zone 1 (Figure 8), the BURL-2 coring site near the north-central shore was close to reed-marsh communities dominated by *Phragmites* and other grasses, associated with *Typha* and marsh herbs. Salt-marsh is indicated by abundant Chenopodiaceae pollen (Peglar et al., 2001) and seeds of *Salicornia europaea*. The water level may have been low before 1900, encouraging the outward spread of reed- and salt-marsh. Macrophytes were few and *Azolla nilotica* floated on the surface. Animal remains (Figure 8) suggest fresh or brackish water with only periodic marine incursions. The zooplankton and diatom assemblages in core BURL-1 also indicate fresh or slightly brackish water (Ramdani et al., 2001b; Flower et al., 2001).

In zone 2 there is a marked local decrease of reed-marsh and salt-marsh macrofossil taxa and freshwater animals. However, the pollen record suggests a regional increase in salt-marsh vegetation (Peglar et al., 2001). *Ruppia* expanded, accompanied by other macrophytes tolerant of brackish water, *Myriophyllum spicatum*, *Potamogeton pectinatus*, and *Najas armata*. Lagoon molluscs, ostracods, and forams showed a major expansion (Figure 8). The abundance of shells in the sediments is reflected in the rise of carbonate from ca. 5% to 20% at the top of zone 2 (Birks et al., 2000). The gastropod *Hydrobia musaensis* is characteristic of fresh and brackish water in Lower Egypt (Brown, 1994). Brackish-water zooplankton are recorded in the equivalent zone of core 1 (Ramdani et al., 2001b). It is possible that a marine incursion around 1900 raised the water level, resulting in a major ecosystem change.

As in Edku Lake, the brackish-water community declined, probably at the same time, after ca. 1920. Around 1940 (zone 3a) fresh-water influence is indicated by the expansion of fresh-water molluscs and animals such as *Plumatella*. Lagoon molluscs and other brackish-water animals, particularly ostracods and forams, remained abundant, however, reflecting continued, probably seasonal, marine influence. *Ruppia* and *Typha* may have been encouraged by eutrophication, and greater productivity is also suggested by the increases in fish remains and nereid jaws. Nereids were important members of the recorded benthic fauna in all the Delta lakes (Samaan et al., 1989) at least up to 1980. *Corbicula* was reported as the most abundant benthic mollusc in Burullus Lake but *Theodoxus niloticus* was confined to the north-central area in 1978–1979 (Samaan et al., 1989). The gastropod *Melanoides tuberculata*, characteristic of bottom mud in disturbed fresh and brackish lakes (Brown, 1994), was frequently recorded living in the core-site area in 1978–1979 (Samaan et al., 1989). *Biomphalaria alexandrina* and *Valvata nilotica* snails are rather intolerant of salinity (Brown, 1994) and were present but rare. *Azolla nilotica* became extinct after ca. 1960 in core 2, about 40 years after its extinction in Edku Lake, where fresh-water influence was greater.

In zone 3b, starting ca. 1963 (Appleby et al., 2001), fresh-water influence increased. This coincides with the completion of the Aswan High Dam. *Potamogeton pectinatus* replaced *Ruppia* and is very abundant today. *Typha* marsh continued to expand near the coring site and fresh-water animals increased while brackish taxa declined (Figure 8). The large numbers of fresh-water molluscs in the surface sediment reflect their living occurrence in the lake today. The spread of *Biomphalaria* in the Delta after 1965 is documented as it is a major carrier of bilharzia (Brown, 1994). Burullus Lake was still brackish as shown by the occurrence of many lagoon mollusca in the surface sediments, and it is brackish today (Fathi et al., 2001). However, pollution and eutrophication have increased since ca. 1965. Pb levels have risen in the top sediment (Birks et al., 2000). Increased nutrients are suggested by the occurrence of *Ceratophyllum* and the frequency and luxuriance of *Potamogeton pectinatus* and *Najas armata*. The diatom assemblage indicates brackish water with relatively stable salinity levels, suggesting that periodic marine influence was reduced (Flower et al., 2001).

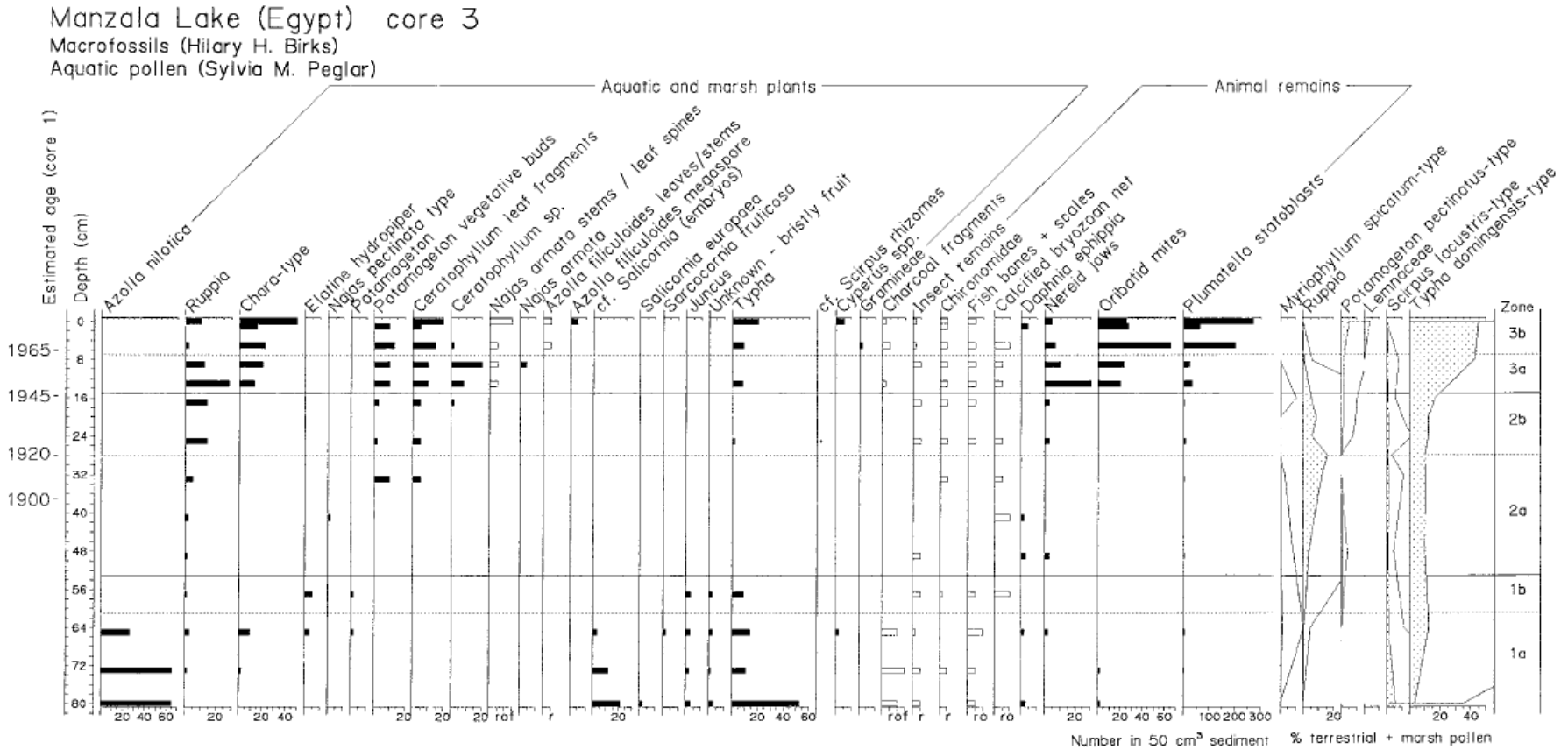

Figure 9. Biostratigraphy of core 3 from Manzala Lake, Egypt. Ages are estimated from the timescale constructed by Appleby et al. (2001). (a) Plant and animal macrofossil concentrations and aquatic pollen percentages. (b) Mollusca concentrations and Ostracoda and Foraminifera percentages. r = rare, o = occasional, f = frequent, a = abundant, v = very abundant.

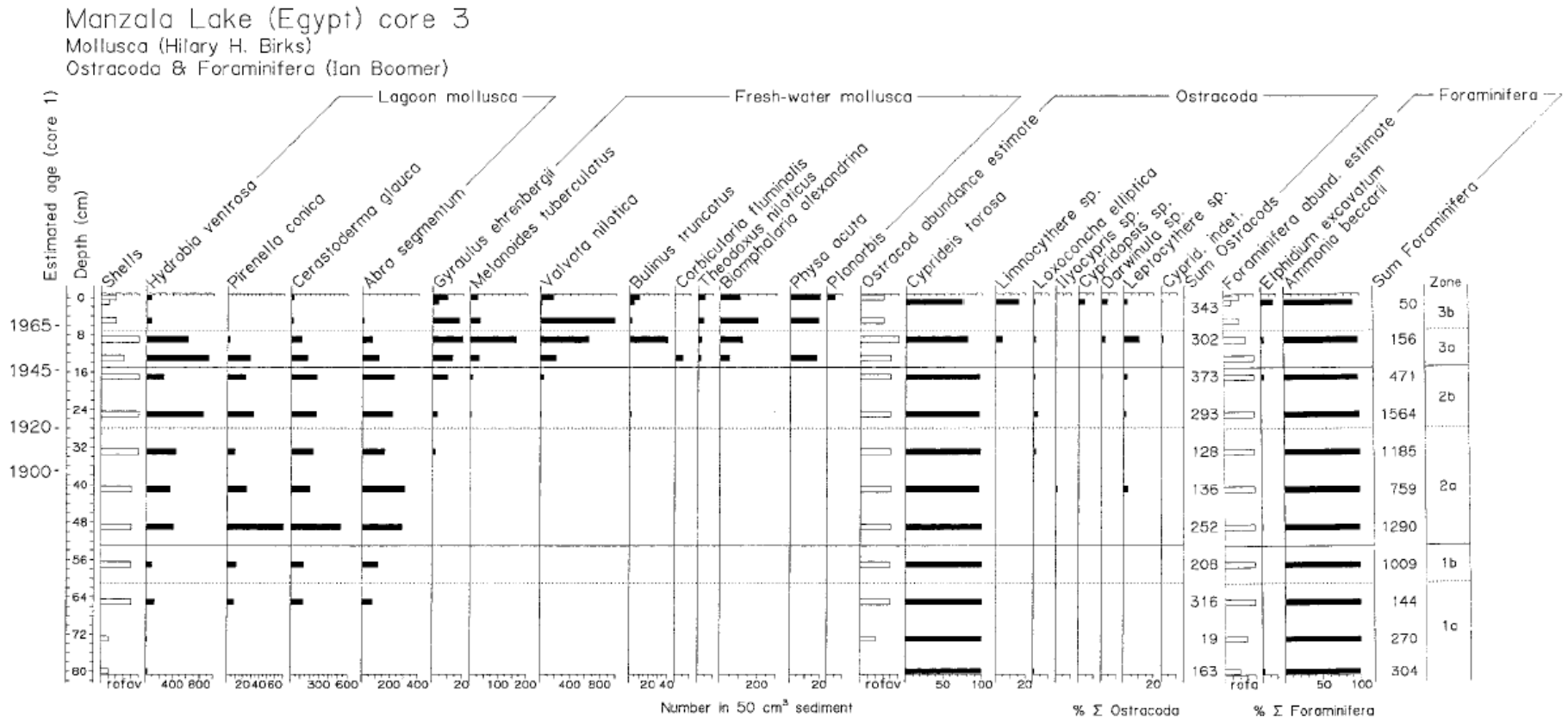

Figure 9. Continued.

Recent changes in Burullus Lake have been smaller than in the other Delta lakes, as a degree of salinity has been maintained. Previous changes in water-level and marine influence have caused much larger changes in the lake ecosystem. However, declining water quality possibly threatens the fishing industry on the lake.

Manzala Lake (Egypt) 31º00'–31º30'N, 31º45'–32º15'E

The lowest sediments of core MANZ-3, located in the south-west area (31º19'N, 31º39'E) (Figure 9a,b) record *Typha*/Gramineae (pollen) reed-marsh and Chenopodiaceae salt-marsh communities with *Sarcocornia fruticosa*, *Salicornia europaea*, and *Juncus*. Together, the occurrence of *Ruppia*, *Chara*-type, the sparsity of fresh-water animals (Figure 9a), and the frequency of foraminifera (Figure 9b), imply brackish water. However, conditions were unsuitable for lagoon molluscs (Figure 9b). In contrast, the abundance of megaspores suggests that conditions were ideal for the growth of *Azolla nilotica* (Figure 9a). However, in the upper part of zone 1, well before 1900, *Azolla* became abruptly extinct, salt-marsh species and *Typha* declined, and lagoon molluscs, ostracods, and forams increased in abundance.

These trends continued in zone 2a. Sparse *Ruppia* and the saline-tolerant *Najas pectinatus*-type were the only macrophytes recorded. The absence of charcoal suggests that the coring site became effectively farther from the shore, perhaps as a result of sea incursion and a water-level rise. Marine influence became strong and the abundance of shells is reflected in the increase in sedimentary carbonate from ca. 5% in zone 1a to ca. 15% (Birks et al., 2000). Marine conditions lasted until ca. 1920 when, in zone 2b, *Ruppia* increased and was joined by *Potamogeton pectinatus* and *Ceratophyllum* (Figure 9a) and fresh-water molluscs and ostracods appeared in the record. Although *Leptocythere* is generally regarded as a marine genus among the ostracods, some species occur in brackish lagoons and estuaries in N.W. Europe and the Mediterranean region. *Loxoconcha elliptica* thrives best at about 10–20_ salinity. A study of Ostracoda in 16 surface samples from Lake Manzala by Slack et al. (1995, 2000) yielded low diversity but high abundance autochthonous assemblages dominated by *Cyprideis torosa*. *Loxoconcha* occurred at 12 stations. *Ammonia beccarii* remained abundant, tolerating 10–40_ salinity.

The marked change at the start of zone 3 at around 1945, reflects increased fresh-water supply to the Delta. *Ruppia* peaked but then declined (Figure 9a). *Potamogeton* (perhaps *P. pectinatus* or *P. crispus*, both present in Manzala Lake today near the coring site), and *Ceratophyllum* increased, and *Najas armata* and *Chara*-type became established. Both *Ceratophyllum* and *N. armata* are represented by fruits as well as vegetative parts. *Typha* also increased, both seeds and pollen, while Chenopodiaceae (pollen), characteristic of salt-marsh vegetation, decreased (Peglar et al., 2001). At the same time lagoon molluscs decreased, and after a peak, nereid jaws also decreased. Freshwater influence is also shown by increases of oribatid mites and *Plumatella* statoblasts, by the occurrence of the ostracods *Limnocythere* and *Darwinula*, and by the marked increase of fresh-water molluscs. Salinity intolerant species such as *Biomphalaria alexandrina* and *Valvata nilotica* may have been living in thickly vegetated drains (Brown, 1994). Increasing plant biomass is probably responsible for the increased organic content of the sediment, while mineral matter derived from Nile silt decreased. Sedimentary carbonate reached ca. 25% reflecting the huge abundance of ostracod and mollusc shells (Birks et al., 2000).

After 1965, in zone 3b, these trends continued. *Ruppia* declined as other macrophytes increased and *Azolla filiculoides* is recorded. However, although *Eichhornia* is abundant in the lake today, it is not recorded in the sediment. The conversion to freshwater and reduction of saline incursions as a result of the Aswan High Dam caused the virtual elimination of lagoon molluscs, a reduction in *Ammonia*, and the expansion of fresh-water ostracods, including *Cyprideis*. The fresh-water gastropod *Biomphalaria alexandrina* increased at the expense of *Bulinus truncatus*, a general feature noted in the Nile Delta following the Aswan High Dam (Brown, 1994). *Physa acuta* is common, and it typically occurs in disturbed, often polluted, habitats, especially near towns (Brown, 1994). *Theodoxus niloticus* was recorded as the most common gastropod living in Manzala Lake in the 1970s (Samaan et al., 1989). As in the other two lakes, south-west Manzala Lake became increasingly fresh after about 1945, with sufficient nutrients to support the expansion of *Ceratophyllum*, although diatom assemblages indicate very mild eutrophication (Flower et al., 2001). The upper sediment is loose and more organic (25% LOI; Birks et al., 2000) than at any previous time. Diatom records from

this part of the lake (Flower et al., 2001; Zalat, 2000) are essentially similar after the Aswan High Dam, but sequences from elsewhere in the lake show that the diatom flora was strongly affected by pollution (Zalat, 2000).

Conclusions

All the CASSARINA lakes have shown major changes over the last 100 years. Some undoubtedly have natural causes, such as drought periods or modifications of the sea/fresh-water balance. The ecosystems have responded and have reached a new balance. However, as technology has developed, human activities have had an increasing impact. The rate and size of the impact have sometimes been too great for the ecosystems to adjust, and dramatic changes have occurred. Water withdrawal for agricultural irrigation is one of the most serious threats. It was complete at Merja Bokka (Morocco) in the late 1990s and the lake dried up. A valuable site with high biodiversity and interesting fauna and flora has been lost. In Tunisia, Megene Chitane is being similarly damaged, yet this soft-water lake contains many species that are very rare in N. Africa. Although it is a nature reserve, the catchment origin of its water is not protected. Unless action is taken soon, this lake will also be lost. Garaet El Ichkeul (Tunisia) is an internationally famous wet land with former high bird diversity. Barrages across its main supply rivers have terminated the low-salinity winter phase necessary to maintain the ecosystem, and its biodiversity has severely declined. Even at the Lac de Korba (Tunisia) coastal lagoon, water withdrawal has lowered the regional fresh-water-table, and it is now hypersaline. It also suffers from pollution and increased turbidity, which recently seem to have affected its ecosystem, indicating that its resilience is decreasing. Sidi Bou Rhaba (Morocco) has suffered from increased turbidity as a result of increased algal productivity, so the basin is rapidly filling and the lake is shrinking. The Merja Zerga lagoon (Morocco) has suffered fresh-water and agrochemical inputs, but overall its aquatic ecosystem has been little affected. Its value for bird life has probably been most affected by the degradation of the shore and of its reed-marshes.

The Delta lakes show a common pattern in their recent history. They all turned from brackish to saline conditions before ca. 1900, suggesting a regional event involving incursion of the sea. The eastern Delta especially has been slowly subsiding (Stanley & Warne, 1993). Salinity was reduced after ca. 1920 as the inability of drainage to remove the year-round extra fresh-water supply from the Nile dams raised the fresh-water table. The increased effect of the Aswan High Dam is detectable in them all. Burullus Lake remains slightly brackish today but Edku and SW Manzala Lakes are now quite fresh and eutrophic (Fathi et al., 2001). They all contain diverse and productive ecosystems at present, but water quality is deteriorating as eutrophication and pollution become problematic. The dominance of water hyacinth renders the surface sediments anoxic when such a large biomass decays in winter. An additional large threat to these shallow lakes is the increasing rate of land reclamation. Lake area is reduced and the remaining water is locally stagnant due to isolation of bays from the sea (Zahran & Willis, 1992) combined with ineffective drainage (Waterbury, 1979).

The resilience of three CASSARINA lake ecosystems has been surpassed and they have suffered or will very soon suffer permanent damage. The other lakes have shown more resilience but their ecosystems are changing with the maintained external environmental stresses. The ecosystems of the Egyptian lakes have been dramatically changed, but have responded with a new balance and are sustaining their biodiversity at present near the localities we studied. However, these and all the other lakes have been affected by human impact in various ways, and it is uncertain how much continued impact can be sustained before the ecosystems collapse.

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